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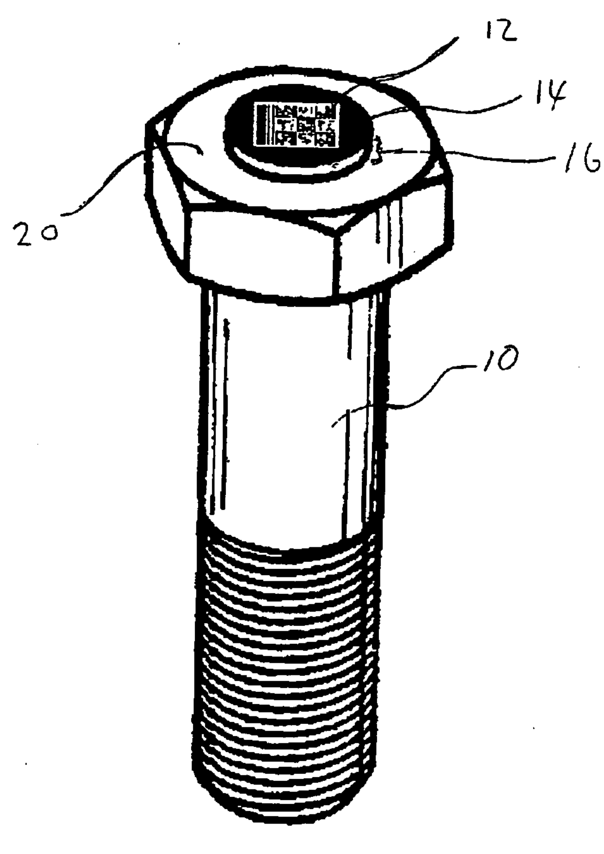
(54) Title: LOAD INDICATING MEMBER WITH IDENTIFYING MARK



(57) Abstract: A load indicating member (10) is provided with a permanent identifying mark which can be read and used to determine ultrasonic (16) measurement parameters specific to the load indicating member to provide more precise and more reliable load measurements by compensating for differences resulting from manufacturing variations in individual load indicating member. The parameters specific to the load indicating member can be stored in coding (12) applied to the load indicating member or in a database that can be accessed remotely.

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LOAD INDICATING MEMBER WITH IDENTIFYING MARK

Background of the Invention

This invention relates to load indicating members and, more particularly, to load indicating members, such as fasteners, having ultrasonic transducers.

In many operations, it is desirable to determine the amount of longitudinal load experienced by a longitudinally stressed member. This information is particularly useful when the longitudinally stressed member is a fastener since the measurement of longitudinal load provides a verification of the existence of a proper joint.

Ultrasonic load measurement is a precise measurement technique for determining load in bolted joints. Pulse-echo techniques with removable ultrasonic transducers have been used in laboratories and for quality control for over thirty years. Historically, however, the practical difficulties in achieving reliable acoustic coupling and in incorporating transducers in tool drives have prevented this technique from becoming a general assembly tightening strategy.

The above coupling difficulties were overcome with permanently attached transducers. U.S. Patent No. 4,846,001 (issued to Kibblewhite) teaches the use of a thin piezoelectric polymer film which is permanently, mechanically, and acoustically coupled to an end surface of a member and used to determine the length, tensile load, stress or other tensile load-dependent characteristic of the member by ultrasonic techniques. Although the invention represented a significant advance over the prior state of the art in terms of performance, ease of manufacture, and manufacturing cost, there are disadvantages with a transducer of this construction. These disadvantages relate to environmental performance, in particular the maximum temperature limitations of the polymer material

which restricts its application, and the possibility of the transducer, fixed to the fastener with adhesive, coming loose and causing an obstruction in, or damage to, a critical assembly.

U.S. Patent No. 5,131,276, issued to Kibblewhite and assigned to Ultrafast, Inc., teaches a load-indicating member having an ultrasonic transducer, including an acousto-electric film, grown directly on the fastener surface (i.e., a piezoelectric thin-film). By growing the acousto-electric film directly on the fastener, the film is mechanically, electrically, and acoustically interconnected to the surface. Permanent ultrasonic transducers not only allow the precise pulse-echo load measurement technique to be used in production assembly but also significantly improve accuracies by eliminating errors that result from axial and radial movement of the removable transducer relative to the bolt and from variations in the coupling media.

All the above-mentioned ultrasonic methods of determining load in a load indicating member require a zero-load measurement in addition to the measurement taken under the desired loaded condition in order to determine the absolute load in the member. Furthermore, all use a direct or indirect measurement of the out-and-return time-of-flight of a longitudinal ultrasonic wave. Holt, U.S. Patent No. 4,602,511, teaches of a method which uses the times-of-flight of both longitudinal and transverse waves to determine the stress in a member without taking a zero-load measurement. This is desirable in the measurement of tensile load in previously installed fasteners, for example.

The use of transverse ultrasonic waves, however, requires both a transducer capable of generating transverse waves and an acoustic coupling media capable of transmitting transverse waves into the member. Special acoustic couplants are required with temporarily attached transducers, since transverse waves cannot generally be transmitted through

liquids. Although adhesives can transmit transverse ultrasonic waves, generation of transverse waves using the polymer film transducers disclosed by Kibblewhite in U.S. Patent No. 4,846,001 has not been demonstrated. Only the permanent ultrasonic transducer technology disclosed by Kibblewhite in U.S. Patent No. 5,131,276 has demonstrated a practical method of making load measurements in fasteners without first taking a zero-load measurement using the method based on measurements of both longitudinal and transverse waves. However, accuracies of only ±15% are typically achievable with this method due to production variations in the material and geometry of the fasteners.

The above-mentioned ultrasonic load measurement methods using longitudinal waves alone are capable of precise measurements when a zero-load measurement is made prior to tightening, with typical accuracies of ±3% documented. Because of the variation in initial lengths of fasteners manufactured using production methods, measurement of installed load at a later time is only possible with ultrasonic load measurements using longitudinal waves alone by recording the zero-load length measurement. Ultrasonic load measurement instruments have the ability to store and retrieve zero-load measurements for later inspection of load.

A means of identifying each fastener for storing and retrieving zero-load length measurements with removable transducer ultrasonic load measurement instrumentation is disclosed by Shigemi et al. in Japanese Patent Application Publication No. 10-086074. Shigemi discloses a method of applying an identifying mark, such as a bar code, on the periphery of the head of the fastener. The bar code is read by an optical bar code reader and the zero-load ultrasonic length measurement is stored in memory in a control device corresponding to the identifying mark on the fastener. When reading the fastener load at a later date, the identifying mark is first read to retrieve the zero-load length

measurement. Zero-load bolt length is the only ultrasonic parameter associated with a specific bolt disclosed by Shigemi. Also, the bar code disclosed by Shigemi is used for identification purposes only and contains no encoded ultrasonic measurement information. While this invention is suitable for a single instrument at a single location, storing and retrieving a zero-load length alone is inadequate in ensuring reliable precise measurement with all fastener types, with different instruments or with different ultrasonic transducers, such as at multiple service locations, for example.

A difficulty in making reliable fastener load measurements with ultrasonic pulse-echo instrumentation arises from the uncertainty in consistently identifying the same echo cycle to which time-of-flight measurements are made. Considerable distortion of the echo waveform can occur, especially with fasteners with large length-to-diameter ratios, primarily due to fastener geometry and stress distribution variations. Vecchio et al., in U.S. Patent No. 6,009,380, disclose a multi-frequency excitation and detection method to improve the reliability of detecting the correct echo cycle when making ultrasonic time-of-flight measurements for determining fastener load. The method stores characteristics of a typical echo waveform as a reference for a particular fastener type. However, variations in echo waveforms from fasteners of the same type can be sufficiently large to prevent this method, using a single reference for a particular fastener type, from working reliably for all fasteners. Consequently, fasteners which deviate significantly from the reference waveform characteristics are unsuitable for reliable inspection with this method and must be screened out in production.

Summary of the Invention

A primary object of the present invention is to

provide a practical method of storing a complete ultrasonic signature for individual high-volume production fasteners in a manner that can be retrieved at a later time by different instrumentation at different locations for reliable precise load measurement for verification of joint integrity.

A further object is to provide a low-cost, permanent, durable mark, such as a high-density bar code, that can be applied to load indicating fasteners, for uniquely identifying individual fasteners.

Another object is to provide an easily accessible database for storing and retrieving fastener ultrasonic signatures, historical tightening data and load data for individual high-volume fasteners.

Yet another object is to provide a low-cost, permanent, durable mark, such as a high-density bar code, that can be applied to load indicating fasteners, capable of storing all the ultrasonic load measurement parameters, unique to a particular fastener, within the code.

Yet another object is to provide a marking system which is practical for use with permanent ultrasonic transducers on fasteners.

Yet another object is to provide a single instrument which automatically identifies a load indicating fastener, retrieves the ultrasonic measurement parameters for the fastener, measures the pulse-echo time-of-flight of an ultrasonic wave, measures the temperature of the fastener and precisely and reliably determines the load in the fastener.

Yet another object is to provide a method of bonding an ultrasonic transducer to a load indicating member using a chemical grafting method.

Yet another object is to provide a load indicating member with a permanent ultrasonic transducer including a magnetic recording material for storing and retrieving data.

Yet another object is to provide a high-density bar code label suitable for use in identifying parts subject

to high temperature and corrosive environments.

The present invention eliminates many of the disadvantages of load indicating members of the prior art and provides additional features and advantages not previously available in load indicating members, load indicating fasteners, load indicating devices and tightening tools.

The load indicating member of the present invention has a permanent identifying mark which can be read and used to determine ultrasonic measurement parameters specific to the load indicating member to provide more precise and more reliable load measurements by compensating for differences resulting from manufacturing variations in individual load indicating members.

In a preferred embodiment of the present invention, a load indicating member has an ultrasonic transducer, permanently mechanically, electrically and acoustically attached to one end of the load indicating member, such that the load indicating member functions as a first electrode. The ultrasonic transducer comprises a piezoelectric element, adjacent to the end surface of the load indicating member, and an electrically conductive layer adjacent to the piezoelectric element, functioning as a second electrode. A high-density two-dimensional optically-read bar code is permanently marked on the surface of the electrode. In this embodiment, the bar code stores not only a unique identification of the load indicating member but also all of the ultrasonic parameters, specific to that load indicating member, required to make precise, reliable load measurements.

One method of making the load indicating member of the preferred embodiment of the present invention includes the steps of providing the load indicating member with its permanently attached ultrasonic transducer, measuring the ultrasonic measurement parameters and marking a bar code, in which the ultrasonic measurement parameters are encoded, on

the top electrode of the transducer.

An alternative method of making the load indicating member of the present invention includes the steps of providing the ultrasonic transducer, comprising the piezoelectric element and electrode layer on which is marked a unique identifying bar code, permanently attaching an ultrasonic transducer to the load indication member, measuring the ultrasonic measurement parameters and storing the ultrasonic measurement parameters in a database associated with the unique identifying bar code.

A method of measuring the load in a load indicating member of the present invention includes the steps of reading the bar code with an optical reader, determining the ultrasonic measurement parameters, making pulse-echo time-of-flight ultrasonic wave measurements, and calculating the precise load.

In another embodiment of the present invention, the permanent mark is applied directly to the load indicating member, and the ultrasonic measurements are made with a removable ultrasonic transducer temporarily attached to the load indicating fastener.

The high-density bar code of the present invention can be marked either with an inkjet marking system or, preferably, using a laser marking system. In an alternative embodiment, a dot code mark is made by drilling holes through the top surface layer with a laser to form the bar code.

The present invention further includes a database of ultrasonic measurement parameters and historical loading data corresponding to each load indicating member, such database being readily interconnected with measurement instruments over a computer network, such as the Internet, and preferably in a manner transparent to the measurement equipment operator.

The present invention further includes an estimation of the load in a load indicating member which

has been elongated beyond its yield point during a loading operation, based on the historical loading data for that load indicating member.

In yet another embodiment of the present invention, a high-density bar code is permanently marked on a thin, durable corrosive-resistant foil and attached to a part as a label for identification purposes.

In yet another embodiment of the present invention, the top electrode of the permanent ultrasonic transducer on the load indicating member is made of a magnetic recording material, such as a nickel cobalt alloy, for example, and the bolt identification, ultrasonic measurement parameters and tightening data are stored and read with magnetic recording and reading devices.

In yet another embodiment of the present invention, chemical grafting is used to permanently bond the layers of film or foil to form a permanent ultrasonic transducer on a load indicating member or a permanent identifying mark on a part.

It is to be understood that both the foregoing summary description and the following detailed description are exemplary, but not restrictive, of the invention.

Brief Description of the Drawings

In the following drawings, like reference numerals refer to like elements throughout.

Figure 1 is a perspective view of a load indicating member according to the present invention.

Figure 2 is a partial view of a load indicating member according to the present invention.

Figure 3 is a top view of the top electrode of the load indicating member of Figure 1.

Figure 4 is a perspective view of an alternative example of a load indicating member according to the present invention.

Figure 5 is a top view of the top electrode of the load indicating member of Figure 4.

Detailed Description of the Invention

A number of measurement parameters are required to determine tensile load, stress, elongation or other measure indicative of tightness of a load indicating member, such as a bolt, rivet or rod, from ultrasonic pulse-echo time-of-flight measurements. These parameters are specific to the load indicating member, the joint in which the load indicating member is installed, the ultrasonic transducer used to transmit and receive the ultrasonic waves and the instrumentation used to make the time-of-flight measurements. These parameters are used to make reliable ultrasonic measurements and determine the relationship between the ultrasonic time-of-flight measurements and load, stress or elongation, and are influenced by, for example, the material, diameter and length of the load indicating member, the effective length on the clamped joint components, the transducer acousto-electric characteristics and instrumentation timing delays. Many of these influences are effectively constant for a specific type of load indicating member and joint, and measurement parameters affected solely by these can be predetermined for a specific joint, stored in the measurement instrumentation and selected at the time of measurement. There are, however, certain parameters that vary with each specific load indicating member due to variations in their manufacturing tolerances. These include, for example, the precise length of the bolt, acoustic properties of the material, internal residual stresses and, in the case of a permanently attached ultrasonic transducer, the acousto-electric characteristics of the transducer.

When a load indicating member, such as a fastener, is being installed from a known zero-load condition, the

parameters needed to compensate for these variations can be determined and used during the loading operation. However, in order to make equally precise load measurements at a later date, for example, measuring the load in pre-installed fasteners, there needs to be a practical way to store and retrieve the parameters specific to each load indicating member. This is provided in accordance with the present invention as follows.

Referring now to the drawings, and more particularly to Figures 1, 2 and 3 thereof, a first embodiment of a load indicating member, and more particularly, a load indicating fastener 10 is described. Load indicating fastener 10 is a fastener with a permanent piezoelectric polymer film transducer attached to one end, an example of which is disclosed in U.S. Patent No. 4,864,001 issued to Kibblewhite, and incorporated by reference herein. The load indicating fastener of the present invention further includes a two-dimensional high-density bar code 12 on top electrode 14 of permanent ultrasonic transducer 16.

The load indicating fastener 10 is formed from a conventional bolt which has been modified to provide an indication of the tensile load, stress, elongation or other characteristic of the bolt during a tightening operation, as well as at various other times during the life of a joint. A thin piezoelectric polymer sensor 18 is permanently, mechanically and acoustically attached to end surface 20 of the bolt. In this embodiment, the piezoelectric polymer sensor 18 is a 9 micron thick, polyvinylidene fluoride copolymer film, manufactured by Measurement Specialties Inc., Valley Forge, Pennsylvania.

In this first embodiment of the present invention, top electrode 14 is a thin metallic foil, specifically approximately 50 micron thick, type 316, full-hard, dull or matte finished stainless steel, which has been treated to provide a black oxide finish. The stainless steel is

available as conventional shim stock which can be specified with a rolled dull or matte finish, or alternatively, chemically treated to provide a dull or matte finish. The black oxide treatment provides an extremely thin (less than 0.5 micron), durable, corrosion resistant, electrically conductive, black coating. A durable, high-resolution bar code can be marked on this surface by removing selected areas of the coating, by conventional laser ablation techniques known in the art, to provide a high contrast mark easily read with conventional, commercially available optical readers.

In this first embodiment, the method of making the load indicating member 10 of the present invention includes the steps of providing a flat surface 20 on one end of the fastener, bonding piezoelectric film 18 to the black oxide coated stainless steel, cutting a 6 mm diameter disc of polymer/stainless steel laminate, bonding the disc to flat surface 20 such that the polymer is adjacent flat surface 20 and the stainless steel foil forms the top electrode 14 of ultrasonic transducer 16, measuring the ultrasonic measurement parameters specific to the load indicating member with ultrasonic pulse-echo instrumentation while the load indicating fastener is at zero-load, encoding measurement parameters and a unique identification into a bar code and permanently marking the bar code 12, with a laser, on the surface of the top electrode 14.

The type of bar code used in this first embodiment is preferably a high-density, two-dimensional code known as a "GoCode", which is a proprietary product of the Gocode Product Corporation, Draper, Utah. This code format provides the ability to store 34 alphanumeric characters on the 6 mm diameter stainless steel top electrode. As will be appreciated by one skilled in the art, there exist many alternative two dimensional bar code formats which could be used to store this data.

In a similar second embodiment of a load

indicating member of the present invention, only a unique identification is encoded in bar code 12, and the ultrasonic measurement parameters associated with load indicating member 10 with this unique bar code are stored in a database, rather than encoded in the bar code itself. Since the data itself is not encoded within the code, unique bar codes can be marked on the stainless steel foil prior to cutting the disc and bonding it to the fastener to form the load indicating member. In this embodiment, the load measurement instruments require the data from the load measurement parameter database in order to make a load measurement in a pre-installed fastener.

An alternative method of providing a permanent durable bar code on the stainless steel of the top electrode is illustrated in Figures 4 and 5. A dot-type bar code 30, such as the proprietary "Snowflake" code available from Marconi Data Systems, Wood Dale, Illinois, is marked on top electrode 32 with holes 34 laser drilled through the foil. Since typically less than 150 10 micron diameter holes are required for the code, their presence has an insignificant effect on the acousto-electric performance of the transducer.

In a third embodiment of the present invention, a load indicating member of the type disclosed in U.S. Patent No. 5,131,276 (Kibblewhite), incorporated by reference herein, is provided in which a piezoelectric thin-film transducer is grown directly on one end of a fastener by a vacuum deposition method, such as magnetron sputtering. Alternatively, a load indicating member is provided in which a piezoelectric thin-film transducer is grown directly on foil by a vacuum deposition method, such as magnetron sputtering, and the transducer is then mechanically, electrically and acoustically attached to the fastener. Also provided is a surface on the top electrode, or elsewhere on the load indicating member, suitable for the marking of a bar code with the above-described marking

methods, to provide the same function as those of the above-described embodiments of the present invention. Alternatively, an additional, thin color-contrasting layer could be vacuum deposited during the manufacturing operation. Parts of this layer could then be selectively removed by laser ablation, in a manner similar to that described above for the stainless steel black oxide layer, to mark the high-density bar code.

In an alternative embodiment of the present invention for use with removable ultrasonic transducers temporarily attached to a fastener, the permanent mark is applied directly to the fastener. The high-density bar code is marked on the fastener after zero-load ultrasonic measurements are made on the fastener and, as with the above-described first embodiment of the present invention, contains encoded fastener-specific ultrasonic measurement parameters. Consequently, load in the bolt can be read by different instruments and at different locations, such as service locations, without access to a database of fastener-specific ultrasonic measurement parameters. The bar code is marked on the fastener with one of the above-described methods.

It will be appreciated by one skilled in the art that there are alternative constructions of the ultrasonic transducer of the present invention. The ultrasonic transducer can be placed on a flat surface in a recess or at the bottom of a hole, for example, with internal drive fasteners. Alternative materials and thicknesses for the top electrode and for the piezoelectric element are possible, and can be selected to produce the desired durability, environmental resistance and acousto-electric performance for a particular application. Additionally, alternative piezoelectric materials, including ceramic piezoelectric materials, can be used and the piezoelectric material can be coated with thin electrically conductive layers to enhance acousto-electric performance. Alternative

thicknesses of the piezoelectric element can also be used. Alternative bar code marking methods, such as inkjet marking, laser marking which heats the surface to discolor the material, and the use of laser-activated or laser-bonded coatings can be used with the present invention. Alternatively, also in the above-described embodiments, the bar codes could be marked directly on the fastener or in the vicinity of the fastener. It will be appreciated by one skilled in the art that the above-described embodiments of the present invention can be used with load indicating members using both longitudinal and transverse waves, such as those described by Kibblewhite in U.S. Patent No. 4,846,001, and with load indicating fasteners provided with ultrasonic reflecting surfaces, such as annular groves, as disclosed by Kibblewhite in U.S. Patent No. 5,029,480.

For those embodiments of the present invention in which the measurement parameters are encoded directly in the bar code, the method of measuring the load in a pre-installed load indicating member includes the steps of reading the bar code with an optical reader, decoding the bar code to retrieve the ultrasonic measurement parameters, making pulse-echo time-of-flight ultrasonic wave measurements, measuring a temperature indicative of the temperature of the load indicating member, and calculating the precise load.

For those embodiments of the present invention in which the bar code is solely a unique identification of the load indicating member, the method of measuring the load in a pre-installed load indicating member includes the steps of reading the bar code with an optical reader, decoding the unique identification of the load indicating member, retrieving the ultrasonic measurement parameters associated with that unique bar code from a database, making pulse-echo time-of-flight ultrasonic wave measurements, measuring a temperature indicative of the temperature of the load indicating member, and calculating the precise load.

When measuring load in a load indicating member of

the present invention during an assembly operation when a recently measured zero-load time-of-flight measurement is available, a measure of temperature is not required, since the change in temperature of the load indicating member during the assembly operation is small and typically has an insignificant effect on load measurements.

Assembly tools for use with load indicating fasteners are known in the art and are described by Kibblewhite in U.S. Patent No. 4,846,001. Such tools are typically standard tools modified to take ultrasonic load measurements during tightening, to compare these measurements with a predetermined desired load, and to stop the tightening process by turning off the tool when the desired load is reached. If such tools are dedicated to a specific fastener type, such as on an automotive assembly line, for example, and are tightening from a zero-load condition, their associated controls can be preset with the ultrasonic measurement parameters specific to the fastener type and, therefore, do not require a bar code reading device.

A load inspection device of the present invention includes a bar code reading device, an ultrasonic pulse-echo time-of-flight measurement device, a device for inputting or measuring a temperature indicative of the temperature of the fastener, and a device for calculating load for recording or display. Preferably, the devices for measuring the bar code, the ultrasonic time-of-flight and the temperature are incorporated in a single probe to provide a simple, efficient measurement device.

In the present invention, ultrasonic measurement parameters and historical loading data corresponding to each load indicating member are uploaded to a database. The database is readily interconnected with measurement instruments over a computer network, such as the Internet, preferably in a manner which is transparent to the measurement equipment operator. The ultrasonic measurement

parameters recorded during the manufacture of the load indicating member are stored in the database. During tightening of the load indicating member with an assembly tool, loading data recorded by the load measurement instrumentation is also uploaded to the database. The database, therefore, contains a complete record of the loading history of the fastener. A fastener load inspection device connected to the database can, for example, not only precisely measure the load in a fastener, but also indicate the drop in load since that fastener was installed. This information is useful in automotive and aerospace preventative maintenance operations.

It will be appreciated by one skilled in the art that the data both encoded in the bar code and stored in the database can be structured to minimize the size of the data records to be stored and transferred. For example, data common to a particular fastener type need only be stored once, and individual fastener bar codes or database records would require only a reference index to this data, such as a fastener part number, plus data specific to the individual fastener.

Ultrasonic load measurements using longitudinal waves can only measure load accurately in fasteners up until the yield point, since beyond that point the elongation is no longer elastic and permanent plastic elongation takes place. The ultrasonic load measurement method which uses both longitudinal and transverse wave times-of-flight, disclosed by Holt in U.S. Patent No. 4,602,511 can, in theory, measure load beyond yield, but is subject to significant errors resulting from the effect of yielding on residual stresses within the fastener. In the present invention, loads beyond yield are estimated from a typical increase in time-of-flight verses yield characteristic for the specific fastener type, determined experimentally and stored in the database. Furthermore, since the complete loading history for each fastener is maintained in the

database, drop in load can be determined precisely from differences between the maximum time-of-flight measurement recorded for the fastener and its then current time-of-flight.

In the above-described embodiments of the present invention, the bonding of the top electrode layer to the piezoelectric polymer 18 and the bonding of the piezoelectric polymer 18 to the top surface 20 of bolt 10 can be accomplished using an adhesive, such as an epoxy adhesive. Alternatively and preferably, this is accomplished with a process known as chemical grafting, such as that developed by the Polymer Research Corporation of America, Brooklyn New York, and described in their Product Bulletin entitled "Insuring your Products Future through Chemical Grafting". Chemical grafting uses an activator to produce a strong covalent chemical bond, rather than a physical bond. The process involves the activation, attachment and polymerization using a material-specific graft initiator-monomer system. The process can be visualized as a growth of "whiskers" onto the substrate. These whiskers attach themselves at activation sites forming polymer chains linked by covalent bonds. Chemical grafting produces such a strong bond that the materials rupture before the bond is broken. The use of chemical grafting, therefore, eliminates the disadvantage of the invention disclosed by Kibblewhite in U.S. Patent No. 4,889,591, that the transducer can come off the load indicating member during the life of the product in which it was installed.

In yet another alternative embodiment of the present invention, a load indicating member with a permanent ultrasonic transducer uses a magnetic recording media as the material for its top electrode. Such a top electrode is manufactured from one of a number of electrically conductive magnetic materials, such as nickel or cobalt alloys and those used for aircraft flight recorders, for example. Data is recorded and read by inductive read/write heads similar

to those commonly used in, for example, computer magnetic disks, audio and video recorders and magnetic strip readers. An advantage of this embodiment of the present invention is that the data, such as the ultrasonic measurement parameters, unique identification number and tightening data can be rewritten, appended to or updated by the measurement instruments.

The metal foil with the bar code marking, used for making the top electrode of some embodiments of the present invention, provides an extremely durable, corrosion and temperature resistant, permanent bar code label or tag and, therefore, this element itself can be used to uniquely identify a component or store a permanent record of critical data associated with an object in applications other than load indicating members. Such applications include the identification of aircraft parts and medical record tags, for example. When used as a label, the foil can be bonded to a component with an adhesive or by using the above-described chemical grafting.

Claims

What is claimed is:

1. An apparatus comprising:

an ultrasonic transducer coupled with an object, for making ultrasonic measurements in the object; and

information storage means applied to the ultrasonic transducer, wherein the information storage means includes markings corresponding to data associated with the object.

2. The apparatus of claim 1 wherein the object is a fastener, and wherein the ultrasonic transducer is attached to the fastener for making measurements indicative of load in the fastener.

3. The apparatus of claim 1 wherein the ultrasonic transducer is permanently attached to the object.

4. The apparatus of claim 1 wherein the ultrasonic transducer is temporarily attached to the object.

5. The apparatus of claim 1 wherein the information storage means is an optical storage media.

6. The apparatus of claim 5 wherein the optical storage media is a color-contrasting mark provided on an exposed surface of the ultrasonic transducer.

7. The apparatus of claim 5 wherein the optical storage media is a reflectivity-contrasting mark provided on an exposed surface of the ultrasonic transducer.

8. The apparatus of claim 5 wherein the optical storage media is a bar code.

9. The apparatus of claim 8 wherein the bar code is a two-dimensional bar code.

10. The apparatus of claim 5 wherein the ultrasonic transducer has an electrically-conductive layer, and wherein the optical storage media is applied to the electrically-conductive layer.

11. The apparatus of claim 5 wherein the optical storage media is a laser-etched marking.

12. The apparatus of claim 5 wherein the optical storage media is a contrast-enhancing coating.

13. The apparatus of claim 5 wherein the optical storage media is a black-oxide coated surface of a metallic foil including portions of the black-oxide coating which are selectively removed by laser ablation.

14. The apparatus of claim 5 wherein the optical storage media is a foil including holes drilled through the foil.

15. The apparatus of claim 1 wherein the information storage means is a magnetic storage media, and wherein the magnetic storage media includes a layer of magnetic material capable of storing data.

16. The apparatus of claim 1 wherein the information storage means contains the data associated with the object.

17. The apparatus of claim 1 wherein the information storage means contains a marking for identifying the object.

18. The apparatus of claim 17 wherein the marking for identifying the object is coupled with an index in a database which contains data relating to the object.

19. The apparatus of claim 18 wherein the database is accessible over the Internet.

20. The apparatus of claim 1 wherein the information storage means contains the data associated with the object and a marking for identifying the object.

21. The apparatus of claim 1 wherein the object is a fastener, and wherein the data includes a zero-load acoustic length of the fastener.

22. The apparatus of claim 1 wherein the object is a fastener, and wherein the data includes parameters for deriving a zero-load acoustic length of the fastener.

23. The apparatus of claim 1 wherein the object is a fastener, wherein the data includes an acoustic signature of the fastener, and wherein the acoustic signature contains parameters for deriving an ultrasonic echo waveform measurement cycle for the fastener.

24. The apparatus of claim 1 wherein the object is a fastener, and wherein the data includes parameters relating to the fastener for calculating load in the fastener from the ultrasonic measurements.

25. The apparatus of claim 1 wherein the object is a fastener, and wherein the data includes parameters relating to a joint into which the fastener is tightened, for calculating load in the fastener from the ultrasonic measurements.

26. The apparatus of claim 1 wherein the object is a fastener, and wherein the data includes a parameter relating to the fastener which is measured during tightening of the fastener.

27. The apparatus of claim 1 wherein the object is a fastener, and wherein the data includes a parameter relating to the fastener which is measured during subsequent loading of the fastener.

28. The apparatus of claim 1 wherein the object is a fastener, and wherein the data includes a parameter relating to the fastener which is measured to determine changes in loading of the fastener.

29. The apparatus of claim 28 wherein acoustic length is measured to determine permanent elongation of the fastener.

30. A load indicating member adapted for ultrasonic load measurement responsive to a bar code marked on the load indicating member, wherein the bar code contains encoded data relating to the load indicating member which comprises data for indicating a zero-load acoustic length of the load indicating member and data for indicating an acoustic signature of the load indicating member.

31. The load indicating member of claim 30 wherein the data for indicating the zero-load acoustic length of the load indicating member is data for deriving the zero-load acoustic length.

32. The load indicating member of claim 30 wherein the data for indicating the acoustic signature of the load indicating member includes parameters for deriving an ultrasonic echo waveform measurement cycle for the load

indicating member.

33. The load indicating member of claim 30 wherein the bar code is permanently attached to the load indicating member.

34. The load indicating member of claim 30 wherein the bar code is temporarily attached to the load indicating member.

35. The load indicating member of claim 30 wherein the load indicating member is a fastener.

36. The load indicating member of claim 30 wherein the bar code is a two-dimensional bar code.

37. The load indicating member of claim 30 wherein the bar code is marked on the load indicating member with a laser.

38. The load indicating member of claim 30 wherein the bar code is marked on a label applied to the load indicating member.

39. A load indicating member adapted for ultrasonic load measurement responsive to a bar code marked on the load indicating member, wherein the bar code contains encoded data which identifies the load indicating member, and a database which contains data relating to the load indicating member, wherein the encoded data of the bar code indexes the data in the database which relates to the load indicating member, and wherein the data in the database which relates to the load indicating member comprises data for indicating a zero-load acoustic length of the load indicating member and data for indicating an acoustic signature of the load indicating member.

40. The load indicating member of claim 39 wherein the data for indicating the zero-load acoustic length of the load indicating member is data for deriving the zero-load acoustic length.

41. The load indicating member of claim 39 wherein the data for indicating the acoustic signature of the load indicating member includes parameters for deriving an ultrasonic echo waveform measurement cycle for the load indicating member.

42. The load indicating member of claim 39 wherein the bar code is permanently attached to the load indicating member.

43. The load indicating member of claim 39 wherein the bar code is temporarily attached to the load indicating member.

44. The load indicating member of claim 39 wherein the load indicating member is a fastener.

45. The load indicating member of claim 39 wherein the bar code is a two-dimensional bar code.

46. The load indicating member of claim 39 wherein the bar code is marked on the load indicating member with a laser.

47. The load indicating member of claim 39 wherein the bar code is marked on a label applied to the load indicating member.

48. The load indicating member of claim 39 wherein the database is accessible over the Internet.

49. An ultrasonic transducer comprising a piezoelectric element attached to an object for making ultrasonic measurements in the object, wherein the piezoelectric element is permanently attached to the object by chemical grafting.

50. The ultrasonic transducer of claim 49 wherein the object is a load indicating member, and wherein the ultrasonic measurements determine a load in the load indicating member.

51. The ultrasonic transducer of claim 50 wherein the load indicating member is a fastener.

52. The ultrasonic transducer of claim 49 wherein the piezoelectric element is a piezoelectric polymer film.

53. The ultrasonic transducer of claim 52 wherein the piezoelectric polymer film is polyvinylidene fluoride.

54. The ultrasonic transducer of claim 49 wherein the piezoelectric element is a piezoelectric ceramic thin film.

55. The ultrasonic transducer of claim 54 wherein the piezoelectric ceramic thin film is zinc oxide grown on a metallic foil by vacuum deposition.

56. The ultrasonic transducer of claim 55 wherein the metallic foil has an exposed surface, and wherein a bar code is marked on the exposed surface of the metallic foil.

57. The ultrasonic transducer of claim 49 wherein the ultrasonic transducer further includes a backing layer formed of an electrically conductive foil.

58. The ultrasonic transducer of claim 57 wherein the piezoelectric element is attached to the electrically conductive foil by the chemical grafting.

59. The ultrasonic transducer of claim 58 wherein the electrically conductive foil has an exposed surface, and wherein a bar code is marked on the exposed surface of the electrically conductive foil.

60. A load indicating device comprising:

a load indicating member marked with a bar code;

an ultrasonic transducer for communicating with the load indicating member;

means for making ultrasonic pulse-echo time-of-flight measurements for communicating with the ultrasonic transducer;

a bar code reader for reading the bar code marked on the load indicating member; and

an Internet connection coupling the means for making ultrasonic pulse-echo time-of-flight measurements and the bar code reader with a database containing data relating to the load indicating member marked with the bar code.

61. The load indicating device of claim 60 wherein the load indicating member is a fastener adapted for load measurement.

62. The load indicating device of claim 61 wherein the bar code contains the data relating to the fastener.

63. The load indicating device of claim 61 wherein the bar code contains a marking for identifying the fastener.

64. The load indicating device of claim 63

wherein the marking for identifying the fastener is coupled with an index in the database which contains the data relating to the fastener.

65. The load indicating device of claim 61 wherein the bar code contains the data relating to the fastener and a marking for identifying the fastener.

66. The load indicating device of claim 61 wherein the data includes a zero-load acoustic length of the fastener.

67. The load indicating device of claim 61 wherein the data includes parameters for deriving a zero-load acoustic length of the fastener.

68. The load indicating device of claim 61 wherein the data includes an acoustic signature of the fastener, and wherein the acoustic signature contains parameters for deriving an ultrasonic echo waveform measurement cycle for the fastener.

69. The load indicating device of claim 61 wherein the data includes parameters relating to the fastener for calculating load in the fastener from the ultrasonic measurements.

70. The load indicating device of claim 61 wherein the data includes parameters relating to a joint into which the fastener is tightened, for calculating load in the fastener from the ultrasonic measurements.

71. The load indicating device of claim 61 wherein the data includes a parameter relating to the fastener which is measured during tightening of the fastener.

72. The load indicating device of claim 61 wherein the data includes a parameter relating to the fastener which is measured during subsequent loading of the fastener.

73. The load indicating device of claim 61 wherein the data includes a parameter relating to the fastener which is measured to determine changes in loading of the fastener.

74. The load indicating device of claim 61 wherein acoustic length is measured to determine permanent elongation of the fastener.

75. A load indicating device comprising:

a load indicating member having an ultrasonic transducer permanently attached to the load indicating member;

a bar code marked on the ultrasonic transducer;

means for making ultrasonic pulse-echo time-of-flight measurements for communicating with the ultrasonic transducer; and

a bar code reader for reading the bar code marked on the ultrasonic transducer.

76. The load indicating device of claim 75 wherein the load indicating member is a fastener adapted for load measurement.

77. The load indicating device of claim 76 wherein the bar code contains a marking for identifying the fastener.

78. The load indicating device of claim 77 wherein the marking for identifying the fastener is coupled with an index in a database which contains data relating to

the fastener.

79. The load indicating device of claim 76 wherein the bar code contains data relating to the fastener and a marking for identifying the fastener.

80. The load indicating device of claim 76 wherein the bar code contains data relating to the fastener.

81. The load indicating device of claim 80 wherein the data includes a zero-load acoustic length of the fastener.

82. The load indicating device of claim 80 wherein the data includes parameters for deriving a zero-load acoustic length of the fastener.

83. The load indicating device of claim 80 wherein the data includes an acoustic signature of the fastener, and wherein the acoustic signature contains parameters for deriving an ultrasonic echo waveform measurement cycle for the fastener.

84. The load indicating device of claim 80 wherein the data includes parameters relating to the fastener for calculating load in the fastener from the ultrasonic measurements.

85. The load indicating device of claim 80 wherein the data includes parameters relating to a joint into which the fastener is tightened, for calculating load in the fastener from the ultrasonic measurements.

86. The load indicating device of claim 80 wherein the data includes a parameter relating to the fastener which is measured during tightening of the

fastener.

87. The load indicating device of claim 80 wherein the data includes a parameter relating to the fastener which is measured during subsequent loading of the fastener.

88. The load indicating device of claim 80 wherein the data includes a parameter relating to the fastener which is measured to determine changes in loading of the fastener.

89. The load indicating device of claim 80 wherein acoustic length is measured to determine permanent elongation of the fastener.

90. A method of making a load indicating member, comprising the steps of:

forming an ultrasonic transducer by mechanically and electrically interconnecting an acousto-electric film to a metallic foil by chemical grafting;

providing a fastener with a head and a shank extending from the head, wherein the shank is subject to elastic deformation when stressed longitudinally such that one portion of the shank moves relative to another portion of the shank; and

mechanically, electrically and acoustically interconnecting the ultrasonic transducer to the fastener by chemical grafting.

91. The method of claim 90 which further includes the step of marking a bar code on the metallic foil.

92. The method of claim 90 which further includes the step of forming the acousto-electric film of polyvinylidene fluoride.

93. A method of making a load indicating member, comprising the steps of:

growing an ultrasonic transducer including an acousto-electric film by vapor deposition on a metallic foil, mechanically and electrically interconnecting the acousto-electric film to the metallic foil;

providing a fastener with a head and a shank extending from the head, wherein the shank is subject to elastic deformation when stressed longitudinally such that one portion of the shank moves relative to another portion of the shank; and

mechanically, electrically and acoustically interconnecting the ultrasonic transducer to the fastener by chemical grafting.

94. The method of claim 93 which further includes the step of marking a bar code on the metallic foil.

95. The method of claim 93 wherein the acousto-electric film is zinc oxide, and which further includes the step of growing the acousto-electric film by vapor deposition.

96. A method of monitoring a load and imparting a torque to a load indicating member, comprising the steps of:

providing a load indicating member which is subject to deformation when stressed such that one portion of the load indicating member moves relative to another portion of the load indicating member, and which includes an ultrasonic transducer permanently mechanically, electrically and acoustically attached to the load indicating member by chemical grafting;

electrically connecting an electronic control unit to the ultrasonic transducer for supplying electronic signals to the ultrasonic transducer and for receiving electronic signals from the ultrasonic transducer;

monitoring the electronic signals received from the ultrasonic transducer by the electronic control unit, providing an accurate measurement of the load in the load indicating member; and

imparting a torque to the load indicating member and removing a torque from the load indicating member in response to the measurement of the load in the load indicating member.

97. The method of claim 96 wherein the load indicating member is a fastener.

98. The method of claim 96 which further includes the step of marking a bar code on an exposed surface of the load indicating member.

99. The method of claim 96 which further includes the step of marking a bar code on an exposed surface of the ultrasonic transducer.

100. An ultrasonic device for monitoring load, for imparting torque and for removing torque, comprising:

a load indicating member subject to deformation when stressed such that one portion of the load indicating member moves relative to another portion of the load indicating member, and which includes an ultrasonic transducer permanently mechanically, electrically and acoustically attached to the load indicating member by chemical grafting;

an electronic control unit electrically connected to the ultrasonic transducer for supplying electronic signals to the ultrasonic transducer and for receiving electronic signals from the ultrasonic transducer, wherein the electronic control unit provides an accurate measurement of the load in the load indicating member responsive to the electronic signals received from the

ultrasonic transducer; and

means for imparting torque to the load indicating member and for removing torque from the load indicating member responsive to the measurement of the load in the load indicating member.

101. The ultrasonic device of claim 100 wherein the load indicating member is a fastener.

102. The ultrasonic device of claim 100 wherein the load indicating member further includes a bar code marked on an exposed surface of the load indicating member.

103. The ultrasonic device of claim 100 wherein the load indicating member further includes a bar code marked on an exposed surface of the ultrasonic transducer.

104. A method of measuring change in acoustic length of a load indicating member, comprising the steps of:

identifying the load indicating member by reading a bar code on the load indicating member with a bar code reader;

retrieving from a database data relating to the identified load indicating member, wherein the retrieved data includes data for deriving a zero-load acoustic length of the identified load indicating member and data for deriving an ultrasonic echo waveform measurement cycle used for acoustic length measurement of the identified load indicating member;

measuring the acoustic length of the identified load indicating member using an ultrasonic transducer and the derived measurement cycle; and

calculating a difference between the measured acoustic length and the zero-load acoustic length and calculating the change in acoustic length of the identified load indicating member from the calculated difference

between the measured acoustic length and the zero-load acoustic length.

105. The method of claim 104 which further includes the step of calculating the load in the identified load indicating member from the calculated change in the acoustic length.

106. The method of claim 104 wherein the load indicating member is a fastener.

107. A method of measuring change in acoustic length of a load indicating member, comprising the steps of:

reading a bar code on the load indicating member with a bar code reader, wherein the bar code contains data for deriving a zero-load acoustic length of the load indicating member and data for deriving an ultrasonic echo waveform measurement cycle used for acoustic length measurement of the load indicating member;

measuring the acoustic length of the load indicating member using an ultrasonic transducer and the derived measurement cycle; and

calculating a difference between the measured acoustic length and the zero-load acoustic length and calculating the change in acoustic length of the load indicating member from the calculated difference between the measured acoustic length and the zero-load acoustic length.

108. The method of claim 107 which further includes the step of calculating the load in the load indicating member from the calculated change in the acoustic length.

109. The method of claim 107 wherein the load indicating member is a fastener.

110. A label for identifying an object, comprising a metallic foil having an exposed surface which is permanently attached to the object by chemical grafting, and a bar code marked on the exposed surface of the metallic foil.

111. The label of claim 110 wherein the bar code is a two-dimensional bar code.

112. The label of claim 110 wherein the bar code is marked on the exposed surface of the metallic foil with a laser.

113. The label of claim 110 wherein the object is a component used in a manufactured assembly.

114. The label of claim 113 wherein the object is a fastener.

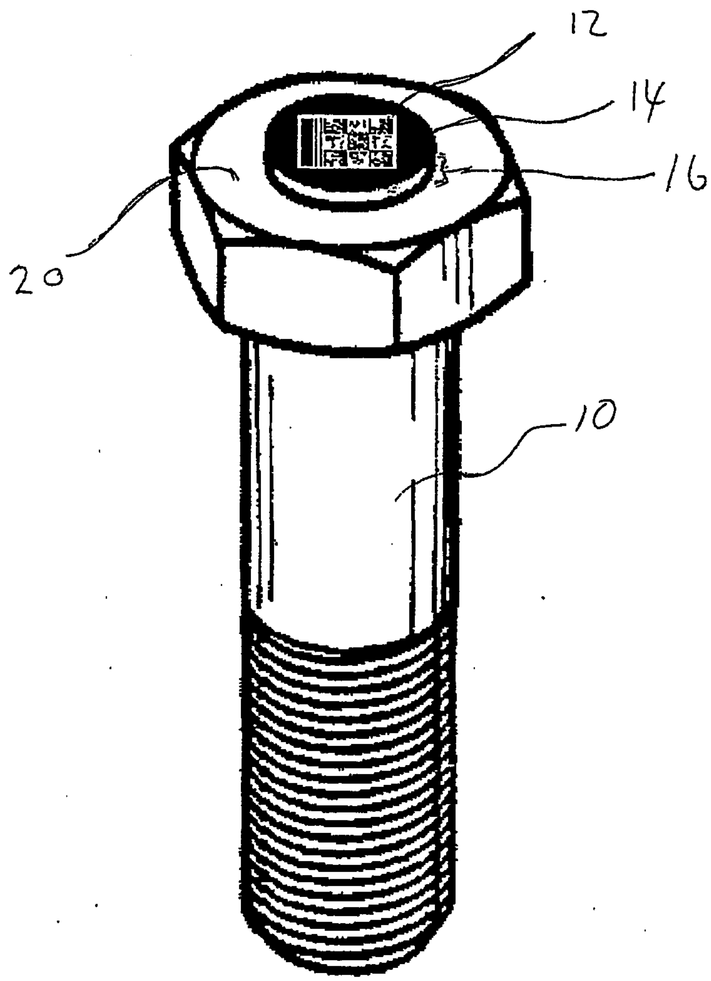

FIG. 1

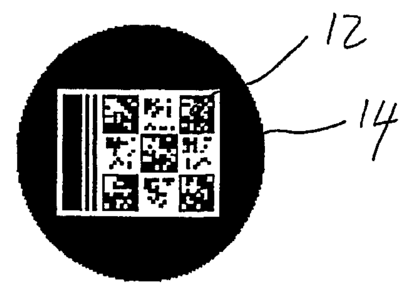

FIG. 3

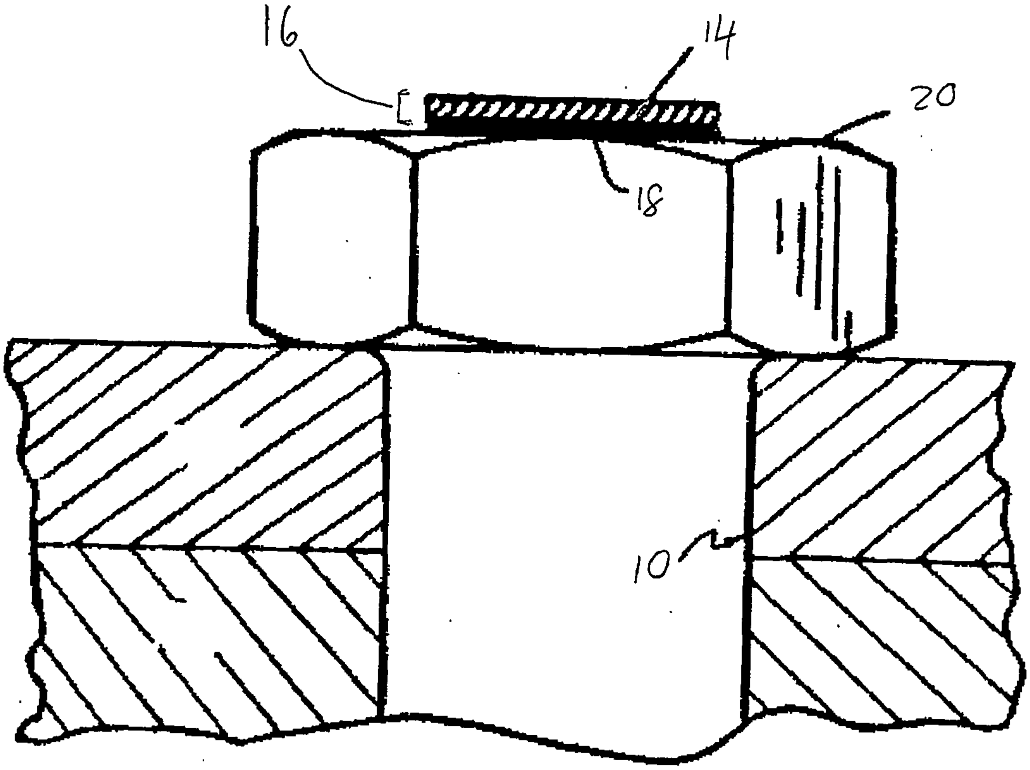

FIG. 2.

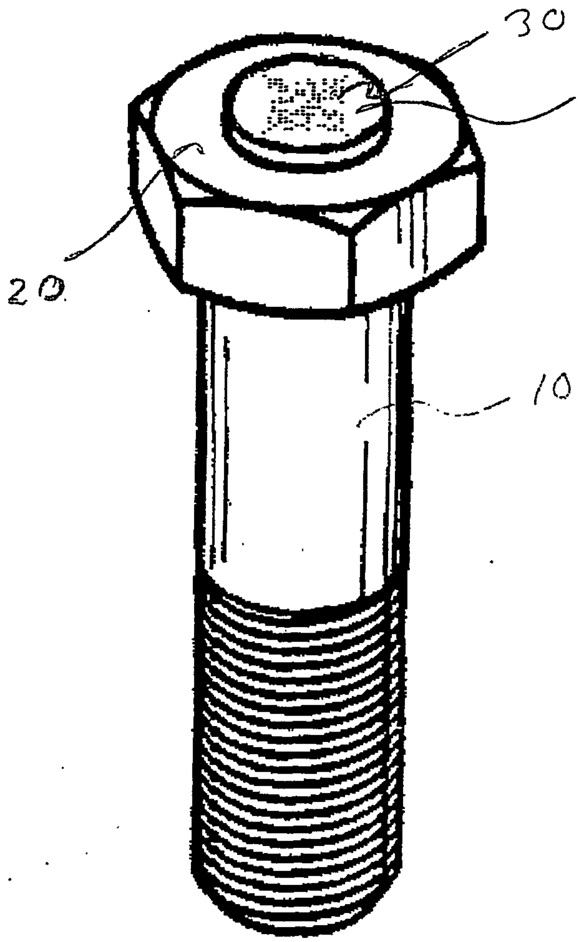

FIG. 4

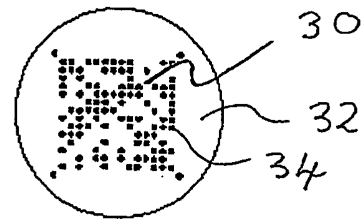

FIG. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US02/03920

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : F16B 31/02
US CL : 73/761
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 73/761

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

East
search terms: ultrasonic, fastener, load, bar-code, optical storage, memory

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4,471,657 A (VORIS et al) 18 September 1984, (18/09/84) see the entire patent	1-4, 15-29, 49-59, 90-98, 100-101N
X	US 5,343,785 A (HOLT et al) 06 September 1994, 06/09/94) see the entire patent.	1-4, 15-29, 49-59, 90-98, 100-101
Y	US 6,078,874 A (PIETYet al) 20 June 2000, (20/06/00) see calim 16.	5-14, 30-48, 60-89, 99 and 102-114
Y	US 6,142,023 A (COLE et al) 07 November 2000, (07/11/00) see claim 4.	5-14, 30-48, 60-89, 99 and 102-114

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search
21 MAY 2002

Date of mailing of the international search report
12 JUN 2002

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